

FREQUENCY RESPONSE EQUALIZATION SYSTEM FOR HEARING AID MICROPHONES

FIELD OF THE INVENTION

5 The invention is related to the field of microphones, and in particular to a method and system to compensate for changes in a microphone's frequency response caused by factors interfering with the receipt of acoustic sound in the microphone, and more particularly, to compensating for changes in a hearing aid microphone's frequency response.

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BACKGROUND OF THE INVENTION

Hearing aids receive and process acoustic sound to stimulate components of the auditory system to cause the sensation of hearing in a patient. Hearing aids are generally categorized into one of two types, namely, 15 externally worn types and implantable types. In addition, implantable hearing aids can be further categorized into fully implantable devices and semi-implantable, e.g. devices that include some implanted components (typically a signal processor and transducer) and some external components (typically a microphone and speech processor).

20 One type of implantable hearing aid utilizes a transducer having a vibratory member implanted within the middle ear cavity that mechanically stimulates the ossicular chain via axial vibrations. In one application of such a device, a microphone receives acoustic sound and generates frequency responses for a speech processor. The speech processor, in turn, processes

the frequency responses according to internal values for the patient to generate a processed signal that drives the transducer to cause the mechanical stimulation and sensation of sound in the patient.

Unfortunately, over time the frequency responses generated by hearing aid microphones can change, thereby affecting the perception of sound to the patient. The changes in the frequency response can be caused by a number of factors. In semi-implantable and externally worn devices for example, dirt and other debris can collect on or around the microphone port affecting the microphone's frequency responses to acoustic signals. In hearing aids having implanted microphones, changes in the tissue surrounding the microphone can affect the microphones frequency response to acoustic signals. In this case, the changes e.g. thickness, density, and compliance in the tissue, typically occur gradually following the implant and directly affect the sound received in the microphone and thus the resulting frequency response generated by the microphone for the speech processor. The changes in the frequency response can result in either a decrease or increase in the perception of sound to the patient depending on the current state of the tissue. For example, when the microphone is initially implanted and tuned to the patient's hearing needs, the tissue is typically soft. Over time, however, the tissue thickens and a fibrous capsule is formed before a stabilized state is reached. As the tissue changes so does the patient's hearing function, requiring the patient to visit an audiologist for additional tuning of the hearing aid.

SUMMARY OF THE INVENTION

In view of the foregoing, a primary object of the present invention is to determine operational characteristics of hearing aid microphones. Another object of the present invention is to provide a hearing aid device that 5 automatically compensates for changes in the frequency responses of hearing aid microphones. Yet, another object of the present invention is to periodically test the frequency response of hearing aid microphones and adjust or equalize the frequency responses to compensate for changes that occur.

In carrying out the above objects, and other objects, features, and 10 advantages of the present invention, a first aspect is provided, which includes a hearing aid having a signal processor, a microphone, and implanted transducer. In a hearing aid according to the subject first aspect; the signal processor processes at least one feedback frequency response from the microphone to generate at least one test parameter. The signal processor uses the at least one 15 test parameter to determine at least one operational characteristic of the microphone, e.g. changes in the frequency response of the microphone. The feedback frequency response is generated by the microphone in response to acoustic feedback in the hearing aid. The acoustic feedback is generated by actuation of the transducer in response to at least one test signal that is provided 20 to the transducer. In this regard, a test signal generator that may be separate or included on the processor may provide the test signal. It should be noted that in the case where a separate signal generator is used, the test signal is provided to the transducer via the signal processor so that the signal processor has

knowledge of the test signal characteristics. Further, in this regard, the processor/signal generator may periodically generate the test signal that produces the feedback in the hearing aid. The periodic generation of the test signal is hereinafter referred to as a test session.

- 5 The feedback is detectable by the microphone as an acoustic sound generated by and carried through one or more components of the auditory system, e.g. the tympanic membrane and ear canal, in response to stimulation of the auditory system by the transducer. The microphone, in turn, generates a frequency response to the feedback, referred to herein as a feedback frequency
- 10 response. The signal processor receives this feedback frequency response from the microphone and uses this signal in combination with the original test signal characteristics to generate one or more test parameters. The one or more test parameters may be stored in an equalization matrix. The equalization matrix is used by the signal processor to adjust the frequency responses generated by the
- 15 microphone in response to ambient acoustic inputs, to compensate for changes occurring in those frequency responses over time, e.g. changes caused by tissue growth around the microphone. As referred to herein, the term acoustic frequency responses refers to frequency responses of the microphone generated in response to ambient acoustic inputs as opposed to the acoustic
- 20 feedback.

Various refinements exist of the features noted in relation to the subject first aspect of the present invention. Further features may also be incorporated in the subject first aspect of the present invention as well. These refinements

and additional features may exist individually or in any combination. Thus, according to one feature, the test signal could be provided at a predetermined frequency to the transducer to generate the acoustic feedback at a predetermined tone. In another example, the test signal could be provided at a plurality of predetermined frequencies, e.g. swept across a frequency range, to the transducer to generate the acoustic feedback at a plurality of predetermined tones. Similarly, the test signal could be one of noise, pseudorandom noise, or a chirp(s).

In another feature the equalization matrix could include one or more delta frequencies. The delta frequencies could represent the difference between the feedback frequency response received in the signal processor and a calibration frequency response (e.g. a pre-determined frequency response stored in a memory device connected to the signal processor) at the same frequency. The calibration frequency response could be included in a calibration matrix that is generated prior to implanting the microphone and includes the microphone's frequency responses relative to a baseline, such as the microphone's frequency responses in a saline solution. The calibration frequency response could also be generated from the original characteristics, e.g. frequency and/or amplitude, of the test signal as provided by the signal processor. In this regard, the delta frequencies could represent differences between the test signal as provided and the test signal as received by the signal processor in the feedback frequency response.

In another feature of the subject first aspect, the signal processor could include logic to protect against abnormal conditions that may be present when a test signal is provided. For example, the signal processor may include an upper and lower threshold frequency response (e.g. upper and lower threshold values stored in a memory connected to the signal processor). In this regard, if the feedback frequency response is outside of the upper and lower threshold frequency response, the signal processor could continue to use a previous feedback frequency response and not generate new delta frequencies for the equalization matrix. If, however, the feedback frequency response is within the upper and lower threshold frequency response the signal processor uses the feedback frequency response to generate the delta frequencies for the equalization matrix. In this manner, abnormal conditions cannot skew the feedback frequency response and equalization matrix as the matrix is not updated if the feedback frequency response is not within the expected range.

In a second aspect of the invention, a method of compensating for changes in the frequency response of a subcutaneous microphone is provided. The method includes at least the steps of conducting a test session to determine changes in the frequency responses of the microphone, generating at least one test measure representative of the changes in the frequency response of the microphone, and using the test measure to compensate for the changes in the frequency response of the microphone. During the test session, a test signal is generated and provided by a signal generator that may or may not be included on a signal processor. As described above, the test signal is detectable by the

microphone causing the microphone to generate a feedback frequency response that can be used by the signal processor to generate one or more test parameters for an equalization matrix. The signal processor then resumes normal operation, wherein it receives and processes acoustic frequency 5 responses from the microphone using the equalization matrix to generate processed signals for the transducer that compensate for changes in the acoustic frequency responses.

Various refinements exist of the features noted in relation to the subject second aspect of the present invention. Further features may also be 10 incorporated in the subject second aspect of the present invention as well. These refinements and additional features may exist individually or in any combination.

In a third aspect of the invention, a frequency equalization system is provided. The frequency equalization system includes at least a signal 15 processor and a microphone that is capable of processing acoustic sounds to generate frequency responses representative of the acoustic sounds. The signal processor may include a test signal generator to generate and provide a test signal that is detectable by the microphone. The signal processor may also include equalization logic to process a feedback frequency response from the 20 microphone representative of the test signal to generate an equalization matrix. Finally, the signal processor may include frequency shaping logic that uses the equalization matrix to process acoustic frequency responses to generate processed signals that compensate for changes in those frequency responses.

Various refinements exist of the features noted in relation to the subject third aspect of the present invention. Further features may also be incorporated in the subject third aspect of the present invention as well. These refinements and additional features may exist individually or in any combination.

5 In a fourth aspect of the present invention, a software product for the frequency equalization system is provided. The software product includes test signal generator instructions that are operational when executed on a processor to generate a test signal for a transducer at a predetermined frequency to produce a predetermined test tone. The software product further includes
10 equalization logic instructions that are operational when executed on the processor to direct the processor to process a feedback frequency response representative of the at least one test tone to generate at least one test parameter. The software product includes frequency shaping logic instructions that are operational when executed on the processor to direct the processor to
15 process acoustic frequency responses to generate drive signals for the transducer that compensate for changes in the acoustic frequency responses. Finally, a storage medium that is operational to store the test signal generator instructions, the equalization logic instructions, and frequency shaping logic instructions is provided.

20 Various refinements exist of the features noted in relation to the subject fourth aspect of the present invention. Further features may also be incorporated in the subject fourth aspect of the present invention as well. These refinements and additional features may exist individually or in any combination.

Numerous additional aspects and advantages of the present invention will become apparent to those skilled in the art upon consideration of the following figures and description.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates one embodiment of a hearing aid configured with a frequency equalization system;

FIG. 2 is a flow chart illustrating an example of the operation of the hearing aid of Figure 1;

10 FIG. 3 is an example of an equalization matrix; and

FIG. 4 illustrates another embodiment of a hearing aid configured with a frequency equalization system.

DETAILED DESCRIPTION

15 Reference will now be made to the accompanying drawings, which at least assist in illustrating the various pertinent features of the present invention. Although the present invention will now be described in conjunction with a fully implanted hearing aid, it should be expressly understood that the present invention is not limited to this application, but rather, only to applications where a 20 microphone or similar device is included. For example, it will be readily apparent to those skilled in the art that the principles of the present invention could easily be applied to other systems including implanted and external microphones, e.g. external or semi-implantable hearing aid devices and/or a microphone implanted

in a patient's throat for purposes of speech, to compensate for dynamic characteristics of the microphone's frequency response.

Figure 1 illustrates one embodiment of a hearing aid 100. The hearing aid 100 includes a signal processor 102, a transducer 108, and a microphone 106.

5 The signal processor 102 is connected to the transducer 108 and the microphone 106, all of which are fully implanted under the skin 110 of a patient. The hearing aid 100 is operational to receive and process acoustic sound in the microphone 106 to generate acoustic frequency responses for the signal processor 102. The signal processor 102 processes the acoustic frequency

10 responses according to programmed speech processing logic and internal values generated from prescriptive parameters for a patient. The processed acoustic frequency responses are provided to the transducer 108, which in turn, causes the transducer 108 to stimulate a component of the auditory system to produce the sensation of hearing for the patient.

15 In a hearing aid, such as hearing aid 100, it usually cannot be avoided that at least a portion of the output signal from the signal processor 102 is provided as feedback over a feedback path, such as path 104. The feedback path 104 usually includes the bones and/or other parts of the skull, or the eardrum coupled with the air in the ear canal. The feedback over the path 104 is

20 often detectable by the microphone 106, thereby causing the generation of a feedback frequency response by the microphone 106.

While such feedback is generally considered undesirable, the present invention makes use of its existence, at least on a temporary basis, to

compensate for another undesirable characteristic of implanted hearing aids.

That is, changes in the acoustic frequency response, over time, generated by the microphone 106. These changes being caused by the changing characteristics, over time, of the tissue surrounding the microphone 106.

- 5 In this regard, the microphone 106 could be any implantable device(s) that is operational to transcutaneously receive and process acoustic sound to generate frequency responses for the signal processor 102. In one example of this embodiment, the microphone 106 could be a conventional omni-directional microphone. The acoustic sound could be that which the microphone 106 is intended to detect under normal operation or acoustic sound generated over the feedback path 104. In the context of the present invention, the term "acoustic frequency response(s)" refer to the frequency response of the microphone generated in response to ambient acoustic sound detected by the microphone.
- 10 The term "feedback frequency response(s)" refer to the frequency response of the microphone generated in response to acoustic sound detected over the feedback path 104. Similarly, the term "calibration frequency response(s)" refer to the frequency response of the microphone generated in response to a baseline or known frequency response. Those skilled in the art will appreciate, however, that while the terms distinguish between different frequency responses of the microphone 106 to illustrate the principles of the present invention, they are all representative of the frequency response of the microphone to an acoustic input.
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The signal processor 102 could be any device or group of devices configured to periodically conduct a test on the frequency response of the microphone 106 to determine if the frequency response has changed. In that regard, the signal processor 102 generates and provides a test signal to the 5 transducer 108 that is detectable by the microphone 106 over the feedback over path 104. The signal processor 102 also processes a feedback frequency response from the microphone 106 to generate at least a single iteration or data set for an equalization matrix. As will become apparent from the following description, the equalization matrix could include several iterations with the 10 current or last generated data set being used until another test is performed.

The signal processor 102 uses the equalization matrix to determine if the frequency response has changed, and if so, to compensate for the changes. The equalization matrix could be any data set that includes test parameters indicative of the difference between the prior frequency response of the 15 microphone 106 and the current frequency response of the microphone 106. It should be noted, however, that the equalization matrix may be a stand alone module or may be incorporated into the frequency shaping tables of the signal processor 102.

The transducer 108 could be any device that is configured to stimulate a component of the auditory system responsive to an input from the signal 20 processor 102. The transducer 108 could be an implanted mechanical, electrical, electromechanical, or acoustic transducer that stimulates the auditory system to produce the sensation of sound for a patient.

Figure 2 is a flow chart illustrating one example of the operation of the hearing aid 100. It should be noted that the following operation could be performed at any time following the implant of the hearing aid 100, but is preferably performed at regular intervals at least until it is determined that the tissue surrounding the microphone 106 has reached a steady state. Thereafter, the time between intervals may be increased as a matter of design choice. Some examples of when the operation could be performed include without limitation, on a daily basis initially after the implant (e.g. during the initial healing and bodies response to the implant) and thereafter on a weekly basis as a stabilized state is reached. Alternatively, the operation may be performed each time the hearing aid 100 is turned on or during an event such as recharging of a power source.

On figure 2, the operation begins at step 200 whereby the signal processor 102 enters a test mode. At step 201, the signal processor 102 generates and provides a test signal to the transducer 108. The test mode could be any mode whereby the signal processor 102 is operational to detect only the feedback frequency response of the microphone 106 representative of the test signal. The test signal could be any signal that is at least eventually detectable by the microphone 106 over the feedback path 104. For example, the test signal could be generated at a predefined frequency to produce at least one predetermined tone. The at least one tone may be audible or inaudible to the patient as a matter of design choice, so long as the tone is detectable as feedback over the path 104 by the microphone 106. In that regard, the test

signal may be in the form of noise or pseudorandom noise or one or more chirps. In a preferred example, the test signal is inaudible to the patient and is swept across a predetermined frequency range to generate a plurality of tones at a plurality of frequencies. In this case, the plurality of tones are sequentially generated beginning with lower frequency tones and ending with higher frequency tones. While it is not necessary that all of the individual test tones be detectable by the microphone 106, the tones should be provided at the different frequencies until the tones are initially detected and thereafter until a representative sampling of the feedback response at different frequencies can be obtained.

At step 202, the microphone 106 generates and provides feedback frequency responses representative of the test signal to the signal processor 102. At step 203, the signal processor 102 uses the feedback frequency responses to generate an equalization matrix for the hearing aid 100. The equalization matrix could be any data set that includes parameters for compensating or equalizing the frequency response of the microphone 106 to negate the effects of changes caused by the tissue surrounding the microphone 106. As will become apparent from the following description, various methods of generating the equalization matrix from the feedback frequency response could be used as a matter of design choice.

At step 204, the signal processor 102 enters a normal operation mode and thereafter uses the equalization matrix to equalize acoustic frequency responses from the microphone 106 according to the internal processing values

for the patient. The equalization of the acoustic frequency responses could be any processing step whereby the signal processor 102 accounts for changes, over time, in the frequency response of the microphone. For example, the signal processor 102 may increase or decrease the gain at individual frequencies 5 according to the internal values for the patient to achieve a desired auditory result. At step 205, the operation ends.

Figure 3 illustrates an example of an equalization matrix, namely equalization matrix 300. The equalization matrix 300 includes a plurality of delta frequencies computed at a plurality of frequencies during a plurality of test sessions. The test sessions, e.g. sessions 1-Nth, are representative of one iteration of the operation described in figure 2. In that regard, during each session, e.g. session (1), a plurality of delta frequencies as exemplified by ΔF_{1_1} - ΔF_{Nth_1} are generated by the signal processor 102 at a plurality of frequencies. These delta frequencies are thereafter utilized by the signal processor 102 until another test session, e.g. session (2), is performed by the signal processor 102 15 and a another set of delta frequencies, e.g. ΔF_{1_2} - ΔF_{Nth_2} are generated.

In a first embodiment of the equalization matrix 300, the delta frequencies, such as the frequency ΔF_{1_1} of the first test session, could be the computed difference between a test tone generated at a pre-determined frequency, e.g. 20 250 Hz, and the frequency of the feedback frequency response representing the test tone as provided to the signal processor 102 by the microphone 106. Similarly, the frequency ΔF_{2_1} would be the difference between a test tone generated at a second pre-determined frequency, e.g. 400 Hz, and the

frequency of the feedback frequency response representing the test tone as provided to the signal processor 102 by the microphone 106. In this manner a plurality of delta frequencies ΔF_1 - ΔF_{Nth} are computed at the different frequencies, which are indicative of changes in the frequency response of the 5 microphone 106 at those frequencies, e.g. by comparison to a known or previous frequency response at the same frequency.

In a second embodiment of the equalization matrix 300, the delta frequencies such as the frequencies ΔF_1 of the first test session, could be the difference between an average of the feedback frequency response for a 10 plurality of test tones generated at the pre-determined frequency, e.g. 250 Hz, and a calibration frequency response for a tone at the 250 Hz frequency. Similarly, the frequency ΔF_2 would be the difference between an average of the feedback frequency response for a plurality of test tones generated at the pre-determined frequency, e.g. 400 Hz, and a calibration frequency response for a 15 tone at the 400 Hz frequency. The calibration frequency responses for the various frequencies could be generated by the method of figure 2, during tuning and testing of the hearing aid 100 immediately following the implant procedure. Thereafter, the method of figure 2 could be used to generate the equalization matrix 300 using the calibration matrix generated during the initial tuning and 20 testing of the hearing aid 100.

Advantageously, using the average of a plurality of test tones generated at a pre-determined frequency prevents an inaccurate frequency response due to a temporary abnormal condition from skewing the delta frequencies. For

example, if the test session is performed while a patient is approaching a sound reflecting article, a significant change in the feedback frequency response that is not indicative of the normal response could be produced resulting in a skewed result. If the condition is removed during the test session, the average over the plurality of test tones results in the generation of a substantially accurate delta frequency. As will become apparent from the following description, further methods may be used to accommodate the case where the abnormal condition is not of a temporary nature, but rather, persists throughout the course of the test session.

- 10 In a third embodiment of the equalization matrix 300, the delta frequencies such as the frequencies ΔF_{11} of the first test session, could be the difference between a single test tone or the average of a plurality of test tones generated at the pre-determined frequency, e.g. 250 Hz, and a baseline frequency response at the 250 Hz frequency for the microphone 106. Similarly, 15 the frequency ΔF_{21} is the difference between a single test tone or the average of a plurality of test tones generated at the pre-determined frequency, e.g. 400 Hz, and a baseline frequency response at the 400 Hz frequency for the microphone 106. The baseline frequency response(s) could be generated by the hearing aid manufacturer, and be included in the processing logic of signal processor 102.
- 20 In a fourth embodiment of the equalization matrix 300, the delta frequencies of the first test session $\Delta F_{11} - \Delta F_{Nth1}$ could be used to generate the delta frequencies for the remaining sessions. In this case, the delta frequencies $\Delta F_{11} - \Delta F_{Nth1}$ would be generated by the signal processor 102 during a setup

protocol implemented when the hearing aid 100 is implanted, and thus represent a baseline from which to generate additional delta frequencies, e.g. ΔF_{12} . Thus, ΔF_{12} of the second test session would be the difference between the frequency response of a test tone generated at 250 Hz and ΔF_{11} , which is the baseline 5 frequency response at 250 Hz for the microphone 106. Similarly, ΔF_{22} would be the difference between a test tone generated at 400 Hz and ΔF_{21} , which is the baseline frequency response at 400 Hz for the microphone 106.

Figure 4 illustrates another embodiment of a hearing aid, namely hearing aid 400. Those skilled in the art will appreciate how this embodiment could be 10 combined with the other embodiments disclosed herein to form numerous additional embodiments in accordance with the principles of the present invention.

The hearing aid 400 includes a microphone 404, an analog to digital (A/D) converter 406, a digital signal processor 402, and a transducer 408. The DSP 15 402 includes equalization logic 418, frequency shaping logic 416, and a test signal generator 414 collectively referred to herein as frequency equalization system 420.

The A/D converter 406 is operational to convert analog frequency responses from the microphone 404 to a digital signal for the DSP 402. The 20 feedback path 104 is also included on figure 4 to illustrate that at least a portion of the output signal from the DSP 402 is provided back to the microphone 408 as feedback. Also, shown on figure 4 is a feedback filter that may be present on

some hearing aids as a matter of design choice, and therefore is indicated by the dashed lines.

The test signal generator 414 generates and provides the test signal to the transducer 404. As with the above-described embodiment, the test signal 5 may be a signal that causes the generation of a single test tone or plurality of test tones generated at different frequencies by the transducer 408. The test tones, however, are preferably generated in a frequency domain that does not cause un-damped oscillation in the hearing aid 400. Those skilled in the art will appreciate that this frequency range is a function of the hearing aid type and 10 system design, but is easily determinable from the phase, e.g. a feedback phase of zero (0) degrees is required for oscillation.

The transducer 404 may be an electromechanical transducer having a vibratory member connected to the ossicular chain, e.g. the incus bone. In this type of hearing aid, mechanical energy from the transducer 404, resulting from 15 the test tones is not only provided to the cochlea 410 via the ossicular chain, but is also transmitted to the tympanic membrane. In this regard, the tympanic membrane 414, functions as a speaker diaphragm, converting the mechanical energy to an acoustic feedback signal that is provided over the feedback path 104. Alternatively, the transducer 404 could be any type of transducer that 20 stimulates a component of the auditory system.

The microphone 404 is preferably an omni-direction microphone that detects the acoustic feedback signal and generates a feedback frequency response that is provided to the equalization logic 418 of the DSP 402.

Responsive to receiving the feedback frequency response, the equalization logic 418 determines the time behavior and the frequency behavior of the feedback frequency response from the microphone 404 to generate the equalization matrix 300. In this regard, the equalization logic 418 may also compare the feedback frequency response to an upper and a lower threshold frequency response. The upper and lower thresholds define the range of expected feedback frequency responses from the microphone 404. If the feedback frequency response is outside the upper and lower threshold response, the equalization logic 418 could continue to use the previous feedback frequency response, thereby preventing an abnormal condition from skewing the computed parameters for equalization matrix 300. For example, if the patient is proximate a sound reflecting article or sound absorbing article, the microphone 404 may generate an abnormal feedback frequency response leading to skewed parameters in the equalization matrix 300 if utilized. If the condition persists during the test session, the equalization logic 418 does not update the equalization matrix and the previously determined parameters or default parameters are utilized.

The frequency shaping logic 416 uses the equalization matrix 412 to equalize the frequency response of the microphone 404 to compensate for changes in the frequency response caused by tissue growth. The frequency shaping logic 416 includes the processing steps such as amplification, frequency shaping, compression, etc according to the design of the hearing aid 400. The frequency shaping logic 416 also includes the particular internal values used in the processing generated from prescriptive parameters determined by an

audiologist. Thus, depending on the results realized from the equalization matrix, the frequency shaping logic 416 may perform additional frequency shaping such as increasing or decreasing the gain at frequencies affected by the tissue growth.

5 During a test session, the DSP 402 operates in a limited capacity or test mode to only look at the spectral components of the test signal. Other frequency ranges are temporarily disregarded while the test signal (including the test tone(s)) is generated and analyzed to create the equalization matrix 300. Additionally, in hearing aids including the feedback filter 410, the limited capacity
10 operation would include temporarily disabling or bypassing the filter 410 to ensure that feedback representative of the test single is detectable by the microphone 404. Following the performance of a test session, the DSP 402 resumes normal operation and the frequency shaping logic 416 processes acoustic frequency responses from the microphone 404 using the equalization
15 matrix 300 and programmed processing steps and parameters to equalize the acoustic frequency responses according to changes caused by tissue growth.

The above-described elements can be comprised of instructions that are stored on storage media. The instructions can be retrieved and executed by a processing system. Some examples of instructions are software, program code, and firmware. Some examples of storage media are memory devices, tape, disks, integrated circuits, and servers. The instructions are operational when executed by the processing system to direct the processing system to operate in accord with the invention. The term "processing system" refers to a single

processing device or a group of inter-operational processing devices. Some examples of processing systems are integrated circuits and logic circuitry. Those skilled in the art are familiar with instructions, processing systems, and storage media.

5 Those skilled in the art will appreciate variations of the above-described embodiments that fall within the scope of the invention. As a result, the invention is not limited to the specific examples and illustrations discussed above, but only by the following claims and their equivalents.

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